

CLAIMS

1. A laser light source including a first laser for generating a laser beam of a wavelength λ_1 , a second laser
5 for generating a laser beam of a wavelength λ_2 , and a nonlinear optical crystal that uses the laser beam of the wavelength λ_1 and the laser beam of the wavelength λ_2 as inputs and outputs a coherent beam having a wavelength λ_3 of a sum frequency that satisfies a relationship of
10 $1/\lambda_1 + 1/\lambda_2 = 1/\lambda_3$, and being characterized in that:

the wavelength λ_3 of a sum frequency is a wavelength of 589.3 ± 2 nm that is equivalent to the sodium D line.

2. The laser light source according to claim 1, wherein,
15 representing refractive indices of the wavelengths λ_1 , λ_2 , and λ_3 by n_1 , n_2 , and n_3 , respectively, the nonlinear optical crystal has a periodically poled structure of a period Λ that satisfies

$$2\pi n_3/\lambda_3 = 2\pi n_1/\lambda_1 + 2\pi n_2/\lambda_2 + 2\pi n_2/\Lambda.$$

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3. The laser light source according to claim 2, wherein, the nonlinear optical crystal has a waveguide structure.

4. The laser light source according to claim 1, wherein,
25 the wavelength λ_1 is 976 ± 10 nm and the wavelength λ_2 is 1485 ± 20 nm.

5. The laser light source according to claim 1, wherein, the wavelength λ_1 is 1064 ± 10 nm and the wavelength λ_2 is 1320 ± 20 nm.

5 6. The laser light source according to claim 1, wherein, the wavelength λ_1 is 940 ± 10 nm and the wavelength λ_2 is 1565 ± 35 nm.

7. The laser light source according to claim 4, wherein
10 the second laser for outputting a wavelength $\lambda_2 = 1485\pm20$ nm is a DFB laser.

8. The laser light source according to claim 5, wherein
15 the second laser for outputting a wavelength $\lambda_3 = 1320\pm20$ nm is a DFB laser.

9. The laser light source according to claim 6, wherein
the second laser for outputting a wavelength $\lambda_2 = 1565\pm35$ nm is a DFB laser.

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10. The laser light source according to any of claims 1 through 9, further comprising:

two polarization maintaining fibers coupled to outputs of the first and second lasers, respectively; and

25 a multiplexer for multiplexing outputs of the two polarization maintaining fibers and coupling a multiplexed output to the nonlinear optical crystal.

11. The laser light source according to claim 10, wherein the first and second excitation lasers are semiconductor lasers, and at least one of the two polarization
5 maintaining fibers has a fiber Bragg grating.

12. The laser light source according to claim 11, wherein at least one of the first and second lasers has a first facet that is coupled to the polarization maintaining fiber
10 and a second facet opposite to the first facet, the first facet being specified to have a reflectance of 2% or less and the second facet being specified to have a reflectance of 90% or more.

13. A laser light source including a first laser for
15 generating a laser beam of a wavelength λ_1 , a second laser for generating a laser beam of a wavelength λ_2 , and a nonlinear optical crystal that uses the laser beam of the wavelength λ_1 and the laser beam of the wavelength λ_2 as
20 inputs and outputs a coherent beam having a wavelength λ_3 of a sum frequency that satisfies a relationship of $1/\lambda_1 + 1/\lambda_2 = 1/\lambda_3$, and being characterized in that:

the wavelength λ_1 is 940 ± 10 nm, the wavelength λ_2 is 1320 ± 20 nm, and the wavelength λ_3 of the sum frequency
25 is a wavelength of 546.1 ± 5.0 nm corresponding to a yellow range.

14. A laser light source including a first laser for generating a laser beam of a wavelength λ_1 , a second laser for generating a laser beam of a wavelength λ_2 , and a nonlinear optical crystal that uses the laser beam of the
5 wavelength λ_1 and the laser beam of the wavelength λ_2 as inputs and outputs a coherent beam having a wavelength λ_3 of a sum frequency that satisfies a relationship of $1/\lambda_1 + 1/\lambda_2 = 1/\lambda_3$, and being characterized in that:

the wavelength λ_1 is 980 ± 10 nm, the wavelength λ_2 is
10 1320 ± 20 nm, and the wavelength λ_3 of the sum frequency is a wavelength of 560.0 ± 5.0 nm corresponding to a yellow range.

15. A laser light source, including a first laser for generating a laser beam of a wavelength λ_1 , a second laser for generating a laser beam of a wavelength λ_2 , and a nonlinear optical crystal that uses the laser beam of the
wavelength λ_1 and the laser beam of a wavelength λ_2 as inputs and outputs a coherent beam having a wavelength
20 λ_3 of a sum frequency that satisfies a relationship of $1/\lambda_1 + 1/\lambda_2 = 1/\lambda_3$, and being characterized in that:

the wavelength λ_1 is 1064 ± 10 nm, the wavelength λ_2 is
1320 ± 20 nm, and the wavelength λ_3 of the sum frequency is a wavelength of 585.0 ± 5.0 nm corresponding to a yellow
25 range.

16. A laser light source including a first laser for

generating a laser beam of a wavelength λ_1 , a second laser for generating a laser beam of a wavelength λ_2 , and a nonlinear optical crystal that uses the laser beam of the wavelength λ_1 and the laser beam of the wavelength λ_2 as
5 inputs and outputs a coherent beam having a wavelength λ_3 of a sum frequency that satisfies a relationship of $1/\lambda_1 + 1/\lambda_2 = 1/\lambda_3$, and being characterized in that:

the wavelength λ_1 is 940 ± 10 nm, the wavelength λ_2 is 1550 ± 30 nm, and the wavelength λ_3 of the sum frequency
10 is a wavelength of 585.0 ± 5.0 nm corresponding to a yellow range.

17. The laser light source according to any of claims 13 through 16, wherein, representing refractive indices at
15 the wavelengths λ_1 , λ_2 , and λ_3 by n_1 , n_2 , and n_3 , respectively, the nonlinear optical crystal has a periodically poled structure of a period Λ that satisfies

$$2\pi n_3/\lambda_3 = 2\pi n_1/\lambda_1 + 2\pi n_2/\lambda_2 + 2\pi n_2/\Lambda.$$

20 18. The laser light source according to claim 17, wherein the nonlinear optical crystal has a waveguide structure.

19. The laser light source according to any of claims 13 through 16, wherein the second laser is a DFB laser.

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20. The laser light source according to any of claims 13 through 19, further comprising:

two polarization maintaining fibers coupled to
outputs of the first and second lasers, respectively; and
a multiplexer for multiplexing outputs of the two
polarization maintaining fibers and coupling a
5 multiplexed output to the nonlinear optical crystal.

21. The laser light source according to claim 20, wherein
the first and second excitation lasers are semiconductor
lasers, and at least one of the two polarization
10 maintaining fibers has a fiber Bragg grating.

22. The laser light source according to claim 21, wherein
at least one of the first and second lasers has a first
facet that is coupled to the polarization maintaining fiber
15 and a second facet opposite to the first facet, the first
facet being specified to have a reflectance of 2% or less
and the second facet being specified to have a reflectance
of 90% or more.

20 23. A laser light source including a first laser for
generating a laser beam of a wavelength λ_1 , a second laser
for generating a laser beam of a wavelength λ_2 , and a
nonlinear optical crystal that uses the laser beam of the
wavelength λ_1 and the laser beam of the wavelength λ_2 as
25 inputs and outputs a coherent beam having a wavelength
 λ_3 of a difference frequency that satisfies a relationship
of $1/\lambda_1 - 1/\lambda_2 = 1/\lambda_3$, and being characterized in that:

the wavelength λ_1 is in the range of 0.9-1.0 μm ,
the nonlinear optical crystal has a periodically poled
structure of a single period, and

the wavelength λ_3 of a difference frequency varies
5 between 3.1 μm and 2.0 μm when the wavelength λ_2 varies
between 1.3 μm and 1.8 μm .

24. The laser light source according to claim 23, wherein
the nonlinear optical crystal has a waveguide structure.

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25. The laser light source according to claim 23 or claim
24, further comprising:

two polarization maintaining fibers coupled to
outputs of the first and second lasers, respectively; and
15 a multiplexer for multiplexing outputs of the two
polarization maintaining fibers and coupling a
multiplexed output to the nonlinear optical crystal.

26. The laser light source according to claim 25, wherein
20 the first and second lasers are semiconductor lasers, and
at least one of the two polarization maintaining fibers
has a fiber Bragg grating.

27. The laser light source according to any of claims 23
25 through 26, further comprising:

a temperature controlling device thermally coupled
to the nonlinear optical crystal; and

a temperature control circuit for controlling the temperature of the nonlinear optical crystal by controlling the temperature controlling device.

- 5 28. An optical absorption analyzer that includes laser beam emitting means, a gas cell, and laser beam detecting means and that measures a gas concentration optically, said laser beam emitting means comprising:

10 a first laser for generating a laser beam of a wavelength λ_1 of 0.9-1.0 μm ;

a second laser for generating a laser beam of a wavelength λ_2 ; and

15 a nonlinear optical crystal that has a periodically poled structure of a single period and that uses the laser beam of the wavelength λ_1 and the laser beam of the wavelength λ_2 as inputs and outputs a coherent beam having a wavelength λ_3 of a difference frequency that satisfies a relationship of $1/\lambda_1 - 1/\lambda_2 = 1/\lambda_3$;

20 wherein the wavelength λ_3 of a difference frequency varies between 3.1 μm and 2.0 μm when the wavelength λ_2 varies between 1.3 μm and 1.8 μm .

29. A two-wavelength differential absorption LIDAR that includes a two-wavelength light source for outputting two
25 laser beams having an absorption wavelength and a non-absorption wavelength, respectively, and that measures a gas concentration using an intensity difference

between scattered beams of the respective laser beams from the measured gas, said two-wavelength light source comprising:

5 a first laser for generating a laser beam of a wavelength λ_1 of 0.9-1.0 μm ;

a second laser for generating a laser beam of a wavelength λ_2 ; and

10 a nonlinear optical crystal that has a periodically poled structure of a single period and that uses the laser beam of the wavelength λ_1 and the laser beam of the wavelength λ_2 as inputs and outputs a coherent beam of a wavelength λ_3 of a difference frequency satisfying a relationship of $1/\lambda_1 - 1/\lambda_2 = 1/\lambda_3$;

15 wherein the wavelength λ_3 of a difference frequency varies between 3.1 μm and 2.0 μm when the wavelength λ_2 varies between 1.3 μm and 1.8 μm .

30. A laser light source, comprising:

20 a distributed feedback semiconductor laser for oscillating a laser beam having a wavelength twice the wavelength of one absorption line selected from oxygen absorption lines existing at wavelengths of 759 nm to 768 nm;

25 an optical waveguide having the second-order nonlinear optical effect; and

a polarization maintaining fiber that connects an output of the distributed feedback semiconductor laser

and one end of the optical waveguide.

31. The laser light source according to claim 30, further comprising:

5 a lens that is disposed at the other end of the optical waveguide and collimates a beam emitted from the optical waveguide; and

 a filter that does not allow a beam outputted from the semiconductor laser among the collimated beams emitted
10 form the lens to pass through but allows second overtone light generated in the optical waveguide to pass through.

32. The laser light source according to claim 30, wherein an optical fiber that has a structure capable of guiding
15 therein second overtone light generated in the optical waveguide as a single mode is connected to the other facet of the optical waveguide.

33. The laser light source according to any of claims 30, 31, and 32, further comprising:

 a temperature controlling device thermally coupled to the optical waveguide; and

 a temperature control circuit for controlling the temperature of the optical waveguide by controlling the
25 temperature controlling device.

34. The laser light source according to any of claims 30

through 33, wherein the optical waveguide has a structure such that polarization of a second-order nonlinear optical material is reversed periodically.

- 5 35. The laser light source according to claim 34, wherein the second-order nonlinear optical material is any one of lithium niobium oxide, lithium tantalum oxide, and mixed crystals of lithium niobium oxide and lithium tantalum oxide.

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36. The laser light source according to claim 35, wherein the second-order nonlinear optical material is doped with either zinc or magnesium.